Magnetic Field Exposure Assessment in a Case-Control Study of Childhood Leukemia

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Epidemiologic evaluation of the relation between magnetic field exposures and cancer depends critically on study design, particularly the methods used for exposure assessment. We incorporated a complex magnetic field exposure assessment protocol into a large incident case-control study of childhood leukemia. We measured residential magnetic fields using a standard protocol in current and former homes of 638 cases and 620 controls and determined wire codes for 414 case-control pairs. We chose a time-weighted average of magnetic field measurements in each eligible home, weighted by the time the subject lived in each home as the main exposure metric for each subject. We found that 24-hour bedroom magnetic field measurements adequately characterize children's residential exposure and that measuring other rooms contributes only slightly to the estimate of average residential exposure to magnetic fields. Front door measured fields provide useful exposure information when interior measurements are missing. If feasible, measuring multiple homes in which the subject has resided is preferable to measuring a single home. A similar distribution of wire codes for controls agreeing or refusing to participate in our study implies that risk estimates derived from wire code data will not be influenced by response bias. (Epidemiology 1997;8:575–583)

Keywords: magnetic fields, childhood leukemia, case-control study, exposure assessment, measurements, wire codes.

Several studies,[1–3] but not all,[4–8] report an association between childhood leukemia and proxy measures[9] of extremely-low-frequency (50–60 Hz) residential magnetic field exposures. To date, no study has reported a persuasive increase in risk of childhood leukemia in relation to in-home magnetic field measurements. These studies have been criticized for measuring magnetic fields many years after diagnosis. If measurements fluctuate over time, this delay may have resulted in nondifferential misclassification and obscured a potential association between magnetic fields and childhood leukemia. Magnetic fields measured in homes shortly after diagnosis should better represent levels that subjects were exposed to during the time period relevant to the etiology of childhood leukemia. To evaluate this hypothesis, we measured 60-Hz magnetic field exposures and evaluated other suspected environmental risk factors in a large, comprehensive case-control study of acute lymphoblastic leukemia (ALL) conducted by the Children's Cancer Group (CCG). We measured magnetic fields in various locations for varying lengths of time in current and former homes of eligible subjects to derive our main exposure metric, a time-weighted average of magnetic field measurements in multiple residences. We also diagrammed power lines near residences and classified them according to wire code categories used in previous studies.[1–3] This report describes the utility and comparability of various magnetic field metrics used in the collaborative National Cancer Institute-Children's Cancer Group (NCI-CCG) measurement study.

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Methods

Overview of Case-Control Study and Participation Rates

CCG initiated a detailed evaluation of risk factors for biologically defined subgroups of childhood ALL.[10] CCG investigators enrolled 1,914 newly diagnosed (1989–1993) cases of childhood ALL (ages 0–14 years) nationwide and 1,987 matched controls selected by random-

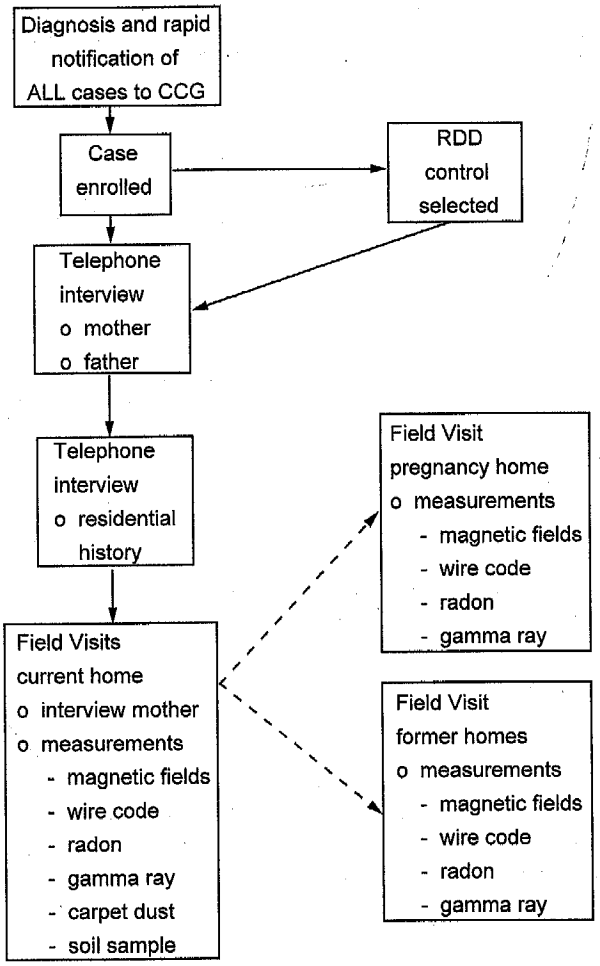

FIGURE 1. Interview and measurement components of the collaborative CCG-NCI case-control study of childhood acute lymphoblastic leukemia. RDD = random digit dialing.

digit-dialing procedures[11] in a comprehensive case-control investigation. The extensive CCG telephone interview of mothers and fathers of subjects was followed by a letter requesting participation in a field measurement investigation focusing on residential magnetic field and other environmental exposures for a subset of 2,234 subjects living in nine states (Illinois, Indiana, Iowa, Michigan, Minnesota, New Jersey, Ohio, Pennsylvania, and Wisconsin). We anticipated high participation rates in this geographical area (U.S. Commerce Department, Bureau of the Census, May 1995 Current Population Survey, unpublished data).

Figure 1 shows the various interview and residential exposure assessment components of the study, and Tables 1 and 2 list the participation rates for each component. CCG interviewed 900 of 942 case parents (28 parents and 2 physicians refused, 12 not included for other reasons) and 973 of 1,292 control parents (253 parents refused, 66 not included for other reasons). We applied these participation rates (that is, 96% for cases and 75% for controls) to the lifetime residential history telephone interview, which yielded response rates of 93% for cases and 73% for controls. We then applied both of these response rates to the mother's in-person interview (88% for cases and 64% for controls) and to the residential magnetic field measurements (78% and 63% for cases and controls, respectively).

CCG provided 851 cases and 825 controls with institutional review board (IRB) approval for the measurement investigation. Seventeen cases and 20 controls had to be excluded from the 942 eligible cases and 1,292 eligible controls because the magnetic field measurement protocol was not approved by the IRBs in their hospitals. We telephoned 832 of 851 eligible case parents (7 refused, 12 not included for other reasons) and 801 of 825 control parents (5 refused, 19 not included for other reasons) to obtain lifetime residential histories. We then conducted in-person interviews with mothers of 788 of 832 cases (27 refused, 17 not included for other reasons) and 699 of 801 controls (78 refused, 24 not included for other reasons).

We considered 832 cases and 801 controls to be potentially eligible for measurements, but we did not measure 65 cases and 76 controls before the end of the field period, resulting in 767 cases and 725 controls eligible for measurements. We measured magnetic field levels in current and former homes of 638 of 767 cases (95 refused, 34 moved too often) and 620 of 725 controls (87 refused, 18 moved too often). Specially trained technicians classified power lines around homes of 414 of 428 case-control pairs (14 eligible pairs excluded because either the case or control, or both, was not coded). Wire coding did not require subject participation. Other residential measurements included natural background ionizing radiation (radon, gamma rays) and pesticide residues in carpet dust and soil.

Eligibility Criteria for Magnetic Field Measurements

We used lifetime residential history to determine eligibility of homes for measurements (Appendix 2). For cases and controls under age 5 years, all homes in which the child resided for at least 6 months (5 months during

TABLE 1. Eligibility and Participation Status of Childhood Acute Lymphoblastic Leukemia Cases and Controls by Study Interview Component

Study Component	Cases			Controls		
	Eligible (No.)	Participated		Eligible (No.)	Participated	
		No.	%		No.	%
Enrolled by CCG, 9-state area	942	900	95.5	1,292	973	75.3
Residential interview, telephone	851	832	97.8	825	801	97.1
Mother's interview, in-person	832	788	94.7	801	699	87.3

TABLE 2. Eligibility and Participation Status of Children with Acute Lymphoblastic Leukemia and Controls for Various Environmental Exposure Assessment Components

Environmental Exposure Component	Cases			Controls		
	Eligible (No.)	Participated		Eligible (No.)	Participated	
		No.	%		No.	%
Magnetic field (MF) levels						
Lifetime/5-year MF measurements	767	638	83.2	725	620	85.5
Pregnancy bedroom MF measurements	554	489	88.3	544	468	86.0
Main home, wire coding	428	414	96.7	428	414	96.7
Pregnancy home, wire coding	199	193	97.0	206	202	98.1
Geomagnetic fields	621	573	92.3	605	502	83.0
Other exposures						
Radon	600	501	83.5	581	442	76.1
Natural background radiation	443	393	88.7	420	327	77.9
Pesticide residues	308	300	97.4	255	250	98.0

pregnancy) before the reference date were eligible for measurements, if the homes collectively accounted for at least 70% of the child's life. We defined the reference date as the date of diagnosis for cases and the corresponding date for matched controls. For children older than age 5 years, financial constraints prohibited us from obtaining lifetime residential magnetic field measurements. Instead, we focused on the 5 years before the reference date, based on the hypothesized promotional effects of magnetic field exposures to cause childhood leukemia.[12] We measured a maximum of two homes for an older child if we could cover at least 70% of the 5-year reference period.

Eligibility Criteria for Wire Codes

Eligible cases and controls had to have lived in one home for at least 70% of their lifetime (age 5 years and under) or 70% of the 5-year reference period (older than age 5 years) for the wire coding component. Otherwise, we excluded the matched pair. Additionally, to evaluate possible response bias in controls, we diagrammed homes of 119 of potential controls who refused to participate during the random-digit-dialing phase of the study.

For all subjects less than 3 years of age at the reference date, regardless of residential mobility, we diagrammed nearby power lines at their mother's longest pregnancy residence. We wanted to ascertain whether pregnancy exposures measured by wire codes relate to leukemia risks in very young children and to assess whether the subjects' residential wire code category differed according to level of residential mobility.

Home Visit: Interview

Beginning in June 1991, trained interviewers conducted in-person, 45-minute interviews with mothers of cases and controls. Interviewers, uninformed of case-control status of the subject, asked questions about the mother's use of selected household appliances during her pregnancy with the study subject, the child's use of selected household appliances from birth until the reference date, pesticide exposure of the mother during pregnancy and of the child during the reference year, other environmental exposures, hobbies of family members, and lifetime medical history of the child.

Home Visit: Magnetic Field Measurements

We developed the measurement protocol based on a personal dosimetry study demonstrating that residential magnetic field area measurements, but not away-from-home (including school/day care) area measurements, are good predictors of children's exposure on a typical weekday.[13] Our final measurement protocol for the present study included a 24-hour magnetic field measurement in the child's bedroom at the site of the bed, 30-second (spot) magnetic field measurements at standardized room locations, and a 30-second (spot) magnetic field measurement within 3 feet outside the front door using the hand-held Emdex-C meter (Electric Field Measurements Company, West Stockbridge, MA). The Emdex-C recorded magnetic fields every second for 30 seconds for the spot measurements. Data collectors obtained spot measurements under both normal-power and low-power conditions. To simulate normal-power conditions, mothers activated appliances (for example, television) that were typically in use during the reference year (that is, 12 months before diagnosis or corresponding reference date for controls for residences lived in at diagnosis and the year before moving for homes lived in earlier) when the child was in the room or when the mother spent time in her bedroom during her pregnancy with the subject. Under low-power conditions, mothers turned off all appliances, if feasible, with the exception of three lights left on for visibility.

When a parent denied access to a home, the data collector requested permission to measure the magnetic fields immediately outside the front door. We found very good to high concordance between such front door magnetic field measurements and within-home measurements for the child's bedroom (Spearman correlation coefficient = 0.77) and the family room (Spearman correlation coefficient = 0.81) in the first 948 homes that we measured (D. R. Friedman *et al*, unpublished data). Therefore, we included subjects residing in homes with only a front door measurement in the magnetic field exposure assessment component of the study.

A hypothesis that specific combinations of static geomagnetic fields and extremely-low-frequency magnetic fields may contribute to the risk of childhood leukemia[14] prompted us to measure geomagnetic fields at standardized room locations (child's bedroom and family room) using a fluxgate magnetometer (FGM-3D1; Walker Scientific, Inc., Worcester, MA).

Diagramming of Residentially Proximate Power Lines and Wire Coding

We used the wire coding scheme developed by Wertheimer and Leeper[15]; this method, used by most studies in the United States, incorporates characteristics of distance and configuration of overhead power lines. The four-category version includes very-high-current configuration (VHCC), ordinary-high-current configuration (OHCC), ordinary-low-current configuration (OLCC), and very-low-current configuration (VLCC).[1] A fifth category, underground (UG) power lines, has been used in some studies.[2,3] Kaune and Savitz modified the original scheme by, among other things, decreasing the number of categories to three to increase the reproducibility of the classification schemes,[16] a modification that we also applied to the data. Two technicians, unaware of case-control status of the subjects, completed standardized forms and diagrammed power lines of eligible homes. We used a computer algorithm to assign the wire code category based on the distance and characteristics of power lines near the residence.

Quality Control

Magnetic Field

Data collectors calibrated the Emdex-C meters before each home visit and serviced them every 6 months. One of us (WTK) periodically reviewed all magnetic field measurements, including detailed 24-hour measurements. Data collectors systematically reviewed the individual data obtained during the 24-hour child's bedroom measurement. We evaluated unusual patterns further for any indication of instrument malfunction.

Wire Coding

Two technicians diagrammed power lines after 5-day initial and annual re-training by one of us (WTK). The technicians independently re-diagrammed annually a random subset of homes, as well as very-high-wire-configuration homes and a selected group of ordinary-high-wire-code homes (R. E. Tarone *et al*, unpublished data). We systematically reviewed all power line diagrams for inconsistencies or errors.

Time-Weighted-Average Magnetic Field Measurement

For each residence lived in by a subject, the home summary measurement consisted of a time-weighted average of magnetic fields based on the 24-hour child's bedroom measurement and 30-second family room and kitchen spot measurements, weighted according to the time spent in these three key rooms (see Appendix 3 for weights), by younger and older children in personal dosimetry studies.[13,17] For missing 24-hour child's bedroom magnetic field measurements, we substituted spot measurements weighted for the time spent in each room. If we did not have any indoor measurements, we used the front door measurement. The main exposure metric for each study subject is a time-weighted average derived from all measured homes per subject and weighted for the proportion of years lived in each residence.

To evaluate the adequacy of the front door measurement as a surrogate for the home summary, we calculated Spearman correlation coefficients between the home summary, the individual room measurements, and the front door measurement for 1,354 homes with a complete set of measurements. Additionally, we compared the proportion of homes classified as ≥ 0.2 μT *vs* <0.2 μT by home summary, the individual room measurements, and the front door measurement only. To investigate the effect of using all eligible residences measured for a subject compared with using the magnetic field measurement for the longest occupied residence only, we examined changes in classification of magnetic field level for 296 subjects who lived in multiple residences.

Results

Eligibility and Residential Mobility

Mothers of 832 cases and 801 controls who completed the residential history reported a similar total number of residences lived in from the beginning of pregnancy through the reference date (Table 3). About one-third of cases and controls (34% and 32%, respectively) lived in only one home from the beginning of the pregnancy through the reference date. Fewer cases (16%) than controls (21%) lived in three homes, whereas slightly more cases had resided in four or more homes (24% *vs*

TABLE 3. Total Number of Residences for Children with Acute Lymphoblastic Leukemia Cases and Controls by Age at Reference Date

Number of Residences*	Number (%)							
	Cases (N = 832): Age (Years) at Diagnosis Date				Controls (N = 801): Age (Years) at Reference Date			
	<5	5–9	10–14	All Ages	<5	5–9	10–14	All Ages
1	185 (38)	79 (34)	21 (18)	285 (34)	174 (37)	68 (29)	11 (11)	253 (32)
2	143 (30)	42 (18)	30 (26)	215 (26)	153 (33)	61 (26)	28 (28)	242 (30)
3	80 (16)	42 (18)	14 (12)	136 (16)	92 (20)	50 (21)	28 (28)	170 (21)
≥4	75 (16)	70 (30)	51 (44)	196 (24)	46 (10)	57 (24)	33 (33)	136 (17)
Total	483 (100)	233 (100)	116 (100)	832 (100)	465 (100)	236 (100)	100 (100)	801 (100)

* Total number of residences ever lived in from pregnancy through the reference date.

TABLE 4. Percentage of Lifetime or Time in 5-Year Period Covered by Magnetic Field Measurements for Acute Lymphoblastic Leukemia Cases and Controls Participating in Study

Percentage of 5-Year Period	Cases (N = 638)		Controls (N = 620)	
	No.	%	No.	%
95.1–100	491	77.0	482	77.7
90.1–95.0	35	5.5	35	5.6
85.1–90.0	36	5.6	30	4.8
80.1–85.0	24	3.8	24	3.9
75.1–80.0	20	3.1	26	4.2
70.0–75.0	32	5.0	23	3.7

17%, respectively). As expected, older children lived in more residences than younger children. Among the older children, more cases than controls lived in only one home (18% *vs* 11%) or in four or more homes (44% *vs* 33%). Only 34 (4%) cases and 18 (2%) controls, however, moved too frequently to be eligible for magnetic field measurements. For 77% of both participating cases and controls, we obtained magnetic field measurements that covered between 95% and 100% of the reference period (that is, lifetime for those age 5 years or younger and 5 years before diagnosis/reference date for those older than age 5 years) (Table 4).

Correlation of Magnetic Field Exposures

For 1,354 homes of cases and controls with a complete set of magnetic field measurements, we found that the front door magnetic field measurement correlated well with the home summary (Spearman correlation coefficient = 0.79) (Table 5). The mean front door measurement (0.111 μT) slightly exceeded the mean for the home summary (0.107 μT). The home summary correlated well with the 24-hour bedroom measurement (correlation coefficient = 0.97), not unexpectedly, because the weighted value for the 24-hour bedroom measurement accounted for 69–79% of the home summary. We found good correlation between the home summary and the 30-second spot measurements for the child's bedroom (correlation coefficient = 0.85), the family room (correlation coefficient = 0.85), and the kitchen (correlation coefficient = 0.74). Spot measurements for all three rooms combined under normal- and low-power conditions correlated very closely with the home summary (correlation coefficients = 0.89 and 0.91, respectively), and we found similar mean levels for normal- (0.103 μT) and low-power (0.098 μT) spot measurements.

Magnetic Field Measurements ≥0.2 μT

We classified similar proportions of the 1,354 homes to magnetic field levels ≥0.2 μT (13.9%) using front door measurements only, compared with the home summary (12.7%) or 24-hour child's bedroom (12.3%) measurements (Table 6, panels A and B). A comparison of the 24-hour child's bedroom measurement with the time-weighted average based on spot measurements for three rooms under normal-power conditions revealed a slightly higher percentage of homes classified as ≥0.2 μT by the 24-hour measurement (12.3%) *vs* the combined spot measurements (10.6%) (Table 6, panel C).

Table 7 compares the distribution of summary magnetic field levels for the longest occupied home *vs* the subject summary (multiple residences) for 296 subjects who each lived in multiple eligible residences. When we used the subject summary, we classified 35 (11.8%) subjects with summary magnetic field level exposures of ≥0.2 μT compared with 46 (15.5%) subjects if the subject single home was used ($P = 0.013$ by McNemar's test). If we had relied on a single residence rather than using the time-weighted average of multiple eligible residences, then one-fourth of the subjects classified with a summary magnetic field level ≥0.2 μT would have been classified differently.

Wire Code Classification of Controls

Overall, we found a similar distribution of wire codes for homes for a sample of 119 control refusals, compared with 406 controls who participated in the study, with a slightly larger proportion of higher wire codes among refusals (Table 8).

Discussion

Expert review groups evaluating previous studies of electric and magnetic fields and their potential relation with

TABLE 5. Correlation between Residential Magnetic Field Measurements in 1,354 Homes

Type of Measurement	Magnetic Field Measurement (μT)				Correlation Coefficient	
	Mean	SD	Minimum	Maximum	Time-Weighted Average	24-Hour Child's Bedroom
Time-weighted average*	0.107	0.109	0.015	0.130		0.97
24-hour child's bedroom	0.106	0.121	0.013	0.160	0.97	
Spots† (normal power)	0.103	0.107	0.013	0.122	0.90	0.83
Spots† (low power)	0.098	0.100	0.015	0.122	0.91	0.84
Spots‡						
Child's bedroom	0.101	0.115	0.013	0.129	0.85	0.83
Kitchen	0.121	0.132	0.014	0.140	0.74	0.66
Family room	0.108	0.121	0.012	0.121	0.85	0.73
Front door	0.111	0.129	0.012	0.171	0.79	0.72

* Time-weighted average measurement is a summary measure of the 24-hour bedroom, 30-second spot family room and kitchen magnetic field measurements weighted for time spent in each room.
† Summary measure of the 30-second spot bedroom, family room, and kitchen magnetic field measurements weighted for time spent in each room.
‡ Normal power.

TABLE 6. Cross-Classification of 1,354 Homes by Type of Measurement for Magnetic Fields <0.2 μT and ≥0.2 μT

A. Time-Weighted Average*

Front Door	<0.2	≥0.2		
<0.2	1,099	67	1,166	(86.1)
≥0.2	83	105	188	(13.9)
	1,182 (87.3)	172 (12.7)		

B. 24-Hour Bedroom

Front Door	<0.2	≥0.2		
<0.2	1,093	73	1,166	(86.1)
≥0.2	95	93	188	(13.9)
	1,188 (87.7)	166 (12.3)		

C. 24-Hour Bedroom

Spots† (Normal Power)	<0.2	≥0.2		
<0.2	1,145	66	1,211	(89.4)
≥0.2	43	100	143	(10.6)
	1,188 (87.7)	166 (12.3)		

* Time-weighted average based on the 24-hour child's bedroom measurement and 30-second family room and kitchen magnetic field measurements, weighted for time spent in each room.
† Time-weighted average of spot measurements based on 30-second child's bedroom, family room, and kitchen magnetic field measurements, weighted for time spent in each room.

childhood cancer have recommended that studies should be conducted in geographical areas with relatively stable populations and an adequate proportion of residences characterized by high wire codes and should include large numbers of subjects.[18–21] Researchers have also suggested that differences in residential stability can result in a potentially biased estimate of cancer risk associated with residential exposure measures.[22,23] We conducted our study in nine midwestern and mid-Atlantic states where the population appears to be relatively stable, compared with most other regions of the United States; 32% of eligible subjects lived in only one home, and another 30% of subjects lived in only two homes between conception and diagnosis/reference date. Only 4% of cases and 2% of controls changed residences too frequently to be eligible for measurements.

Ours is the first study of childhood leukemia to measure systematically current and former homes of subjects covering most of the lifetime for children 5 years and younger and 70% of the 5-year reference period for older children. Data from our analysis comparing single home summary (using longest lived-in residence) with the subject summary from multiple homes indicate that a measurement from a single residence is more likely to be extreme than an average of measurements from multiple residences, resulting in misclassification at higher magnetic field levels.

A recent study reported an association of childhood leukemia with electric fields, based on 56 cases.[24] We chose not to measure electric field exposures, because several larger studies have not found an association between electric field levels and either childhood leukemia or wire code levels.[3,8,25,26] In addition, residential electric field exposures are difficult to characterize accurately, because of the different possible geometries of fields and because the body perturbs the electric field during measurement.[27–29] Although a greater proportion of controls than cases permitted only 30-second front door measurements, we found the estimated mean magnetic field levels derived from front door measurements only slightly higher than the home summary measurement. Therefore, we classified similar proportions of homes ≥0.2 μT using either metric. The result of substituting front door measurements for the fraction (4% of cases and 12% of controls) missing in-home measurements would likely be to diminish any estimate of risk associated with estimated high residential magnetic field levels.

The very high correlation between the home summary measurement and the 24-hour bedroom measurement indicates that the bedroom measurement should provide good information about a child's residential exposure conditions. The additional information gained by 30-second measurements in the family room and kitchen may not be cost effective. The small difference in the mean measurements for normal- and low-power 30-second measurements indicates that low-power measurements are not worth the effort. The front door measurements were the only ones permitted by a small fraction of case families and a meaningful fraction of control families. Therefore, front door measurements could be considered to increase participation rates in studies incorporating magnetic field measurements.

Limitations characterizing the nine-state study that should be considered include possible biases that may result from use of controls selected by random digit dialing. Alternative control groups, for example, both inpatient and outpatient hospital-based controls, controls enrolled by the same physician or managed care practice as cases, and controls enrolled in the same schools as cases, were not feasible owing to confidentiality, privacy, and practical constraints. To characterize

TABLE 7. Time-Weighted Average Magnetic Field Exposure in Multiple Residences *vs* Single, Longest Occupied Residence for 296 Subjects

	Magnetic Field (μT)				
	Multiple Residences				
Single Longest Occupied Residence	<0.065	0.065–0.099	0.100–0.199	≥0.200	Total (%)
<0.065	91	35	9	0	135 (45.6)
0.065–0.099	13	25	10	1	49 (16.6)
0.100–0.199	0	13	51	2	66 (22.3)
≥0.200	0	0	14	32	46 (15.5)
Total (%)	104 (35.1)	73 (24.7)	84 (28.4)	35 (11.8)	296 (100)

TABLE 8. Distribution of Residences by Wertheimer-Leeper Classification of Wire Codes among Potentially Eligible Controls Who Refused Participation* *vs* Residentially Stable Controls†

Wertheimer-Leeper Wire Code Category‡	Potential Controls RDD Refusals (N = 119)		Residentially Stable Controls (N = 406)	
	No.	%	No.	%
UG	16	13.4	75	18.5
VLCC	27	22.7	100	24.6
OLCC	42	35.3	116	28.6
OHCC	24	20.2	90	22.2
VHCC	10	8.4	25	6.2

* Refused participation during random digit dialing (RDD) for control selection.
† Subjects resided in one home during ≥70% of 5 years before reference date.
‡ UG = underground or buried power line; VLCC = very-low-current configuration; OLCC = ordinary-low-current configuration; OHCC = ordinary-high-current configuration; VHCC = very-high-current configuration.

children ascertained using random digit dialing, we collected extensive sociodemographic and socioeconomic information to adjust for any major case-control differences in these factors. Additionally, we observed a similar distribution of wire codes of homes for potential controls who refused to participate at random digit dialing enrollment and those controls who participated. This finding indicates little influence on risk estimates due to response bias.

Other limitations characterizing this and earlier studies include reliance on postdiagnosis measurements and lack of information about the biological relevance of the magnetic field measurement metric used. We generally obtained measurements within 24 months after diagnosis, however, compared with several years or decades in other studies.[2,3,9] Although the biologically relevant metric, if any, is not known, two personal dosimetry studies have confirmed that the area measurements selected for residences correlate very well with personal magnetic field exposure for young children.[13,17] Using data obtained with the Emdex-C meter, we developed measures of time-weighted-average exposure and short-term (1-second) and longer-term (30-second) temporal magnetic field variability. We were unable, however, to separate magnetic fields into their frequency components [for example, into fundamental (60 Hz) and harmonic (120 Hz, 180 Hz, 240 Hz, etc) components]. In addition, we obtained no information about transient magnetic field events with durations of less than about 0.05 second.

Our study includes a substantially larger number of subjects whose homes were measured than in previous studies, similar rates of residential mobility among the cases and controls, information on potential confounding variables, and a comprehensive set of magnetic field measurements, based on a previously conducted personal dosimetry study[13] and confirmed in another personal dosimetry study of 64 controls.[17] We measured magnetic field levels in multiple locations in multiple homes per subject and included additional assessments for quality control purposes in all of the measurement components of the study.

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Appendix 1

TABLE A1. Participating Principal Investigators: Children's Cancer Group

Institution	Investigator	Grant No.*
Group Operations Center, Arcadia, CA	W. A. Bleyer A. Khayat H. Sather M. Krailo J. Buckley D. Stram R. Sposto	CA13539
University of Michigan Medical Center, Ann Arbor, MI	R. Hutchinson	CA02971
Rainbow Babies & Children's Hospital, Cleveland, OH	S. Shurin	CA20320
Children's Memorial Hospital, Chicago, IL	E. Baum	CA07431
Children's Hospital of Columbus, OH	F. Ruymann	CA03750
Children's Hospital of Pittsburgh, PA	J. Mirro	CA36015
University of Minnesota, Minneapolis, MN	W. Woods	CA07306
Children's Hospital of Philadelphia, PA	A. Meadows	CA11796
James Whitcomb Riley Hospital for Children, Indianapolis, IN	P. Breitfield	CA13809
Children's Hospital Medical Center, Cincinnati, OH	R. Wells	CA26126
University of Iowa Hospitals & Clinics, Iowa City, IA	R. Tannous	CA29314
Mayo Clinic, Rochester, MN	G. Gilchrist	CA28882
University of Medicine & Dentistry of New Jersey, Camden, NJ	M. Donaldson	
Wyler Children's Hospital, Chicago, IL	F. L. Johnson	

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Appendix 2

Eligibility Criteria for Exposure Assessment

1. Magnetic Field and Geomagnetic Field Measurements

A. Children under Age 5 Years at Reference Date

All homes were measured in which the subject resided for at least 6 months before the reference date, provided that they collectively accounted for at least 70% of the child's life. Pregnancy home was measured if the mother lived there at least 5 months when pregnant with the subject.

B. Children Age 5 Years and Older at Reference Date

All homes resided in for at least 20% of the 5 years before the reference date (that is, resided in for 1 year or more) were eligible for measurement, but, at most, two homes were measured, and total residential time in these two homes combined had to add up to at least 70% of the 5-year period.

2. Radon Measurements

Subject had to meet eligibility requirements for magnetic field measurements. Radon detectors were placed in up to three rooms, if the rooms of interest were not above the third floor of the home, and the subject or occupant had no plans to move within 3 months of detector placement.

3. Gamma Radiation Detectors

Subject had to meet eligibility requirements for magnetic field measurements. Detectors were placed in up to three rooms, and the subject or occupant had no plans to move within the next 3 months.

4. Pregnancy Home Measurement

A pregnancy home had to have been lived in for at least 5 months while the mother was pregnant with the subject. The measurement was obtained in the bedroom in which the mother slept for most of the time while pregnant with the child.

A. Children under Age 5 Years at Reference Date

If the home was resided in during the pregnancy for at least 5 months, the home was measured, and the measurement was obtained in the bedroom in which the mother slept for most of time while pregnant with the child.

B. Children Age 5 Years and Older at Reference Date

If any of the homes were eligible and measured *and* the mother was pregnant with the child in that home for at least 5 months

of the pregnancy, then the bedroom in which the mother slept while pregnant was measured.

5. WIRE CODE DIAGRAMMING

Eligibility was based on matched sets of cases and controls.

A. Children under Age 5 Years at Reference Date

The home in which the subject lived the longest was diagrammed if both the case and control each lived in his or her home for at least 70% of the subject's life.

B. Children Age 5 Years and Older at Reference Date

The case and control each had to have lived in his or her home for 70% of the 5-year time period.

C. Pregnancy Home

For all subjects less than age 36 months at reference date, homes in which the case or control mother was pregnant with the subject for at least 5 months were measured.

6. HOUSE DUST AND SOIL SAMPLES

At the time of measurement, cases and controls had to have lived in the same home as during the reference year. Subject had to be age 12 months or older at reference date. For subjects age 3 years and older at reference date, subject had to have lived in the home since 12 months of age for a minimum of 3 years. For subjects age 12–35 months at reference date, subject had to have lived in the home since 6 months of age for a minimum of 24 months.

Appendix 3

Weights for Time-Weighted-Average Magnetic Field within a Home

CHILDREN UNDER AGE 9 YEARS

$$\frac{0.431\ \text{bedroom} + 0.160\ \text{family room} + 0.035\ \text{kitchen}}{0.626}$$

CHILDREN AGE 9 YEARS AND OLDER

$$\frac{0.396\ \text{bedroom} + 0.083\ \text{family room} + 0.021\ \text{kitchen}}{0.500}$$

Weights are based on the typical amount of time spent by the child in the room based on two personal dosimetry studies.[13,17] For example, children under age 9 years typically spent 43% of their 24-hour day in their bedroom, whereas older children typically spent 39% of their day in their bedroom. The denominator is the sum of the weights. The remainder of the time was spent in other rooms or outside the home.